SD2 – A COMETARY SOIL DRILL AND SAMPLER DEVICE

C. DAINESE, A. ERCOLI FINZI, *Dipartimento Ingegneria Aerospaziale, Politecnico di Milano via la Masa 34, 20156 Milano*

ABSTRACT

In this paper the problem of in situ planetary analysis is afforded by describing the state of art and presenting the space mission Rosetta devoted to the exploration of comet 67P/Churymov-Gerasimenko. Main characteristic of SD2, Sampler Drill and Distribution Subsystem device, and its activities, planned for commissioning and for Mission Plan realization, are illustrated.

1. INTRODUCTION

For centuries comets had inspired awe and fear. Many ancient civilizations saw them as carriers of death and disasters, omens of great social and political upheavals.
Nowadays, instead, the comets study is a "key point" to answer some questions that are still open, for example the origin of the Solar System and the birth of life on Earth [1].
In order to answer these questions it is necessary to spent some time near or on a comet to study its evolution.
Our knowledge of comets and asteroids has improved over the last twenty years. The major milestones were undoubtedly the first fly-bys of the Halley comet, figure 1, by ESA's Giotto and Russian Vega probes in 1986. In 1991, NASA's Galileo spacecraft made the first near encounter coming from the asteroids main-belt, Gaspra, on its way to Jupiter and pictured the crash of comet on Jupiter.

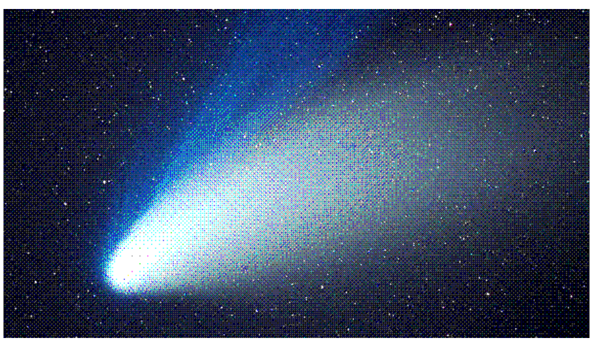

Fig. 1: Halley comet image

Comets are supposed to be small icy bodies, usually only few kilometres across. Many scientists think that comets have kept a record of the physical and chemical process that occurred during the early evolution of our Solar System. Moreover these primitive bodies have not changed since their creation because they have not been altered by internal heating and spend most of their time far from the Sun.
Comets also could contain complex organic compounds which, some scientists believe, may have provided the raw material from which life on Earth evolved. In fact their basic ingredients are dust on the surface, followed by carbon, hydrogen, oxygen and nitrogen. As known, these elements mate up nucleic acids and amino acids [2], the essential ingredients for life as we know it.
For that, the study of the comet nucleus properties, its dynamic characteristics and their chemical composition will help us to understand when and how life on Earth began [3].

To this aim, by the end of 1993, the European Space Agency decided for the Rosetta mission to be the third "cornerstone" of its scientific program "Horizon 2000".

2. ROSETTA MISSION

Rosetta Mission [4] is made up by two systems: an orbiter, Rosetta, and a lander, Philae [5] (figure 2) In fact the Rosetta spacecraft (figure 3), so named in honour of the Rosetta stone that allowed egypthologists to decipher mysterious hieroglyphics, is composed by the orbiter, a pseudo cube of 2.8 x 2.1 x 2.0 metres, on which all subsystems and payload equipment are mounted, and by the lander, a pseudo hexagonal prisme.

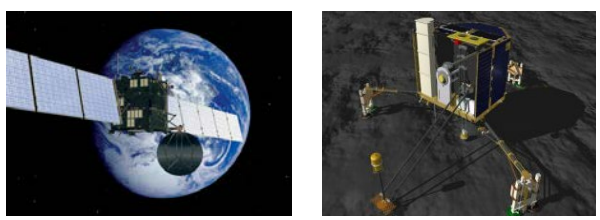

Fig. 2: Artist's impression of the Rosetta Orbiter and of the Philae Lander

Its journey has started 2004, 2[hd] March and it will reach, in 2014, the 67P/Churyumov-Gerasimenko comet at about 450 millions kilometres from the Earth.
During its trip, Rosetta will make three Earth fly-bys, one Mars fly-by and two Asteroid fly-bys. The most difficult phase of the Rosetta mission is the final rendezvous with the fast-moving comet. The mission time line is showed in table 1.

Tab. 1: Mission Time Line

Event	Nominal date
Launch	March 2004
First Earth gravity assist	March 2005
Mars gravity assist	February 2007
Second Earth gravity assist	November 2007
Third Earth gravity assist	November 2009
Rendezvous manoeuvre	May 2014
Global Mapping	August 2014
Lander delivery	November 2014
Perihelion Passage	August 2015
Mission End	December 2015

The Rosetta probe will fly with the comet during a part of its orbit and will enable to study the nucleus as well as its evolution through its approach to the Sun, by remote sensing techniques success and a lander will be ejected for the analysis of the soil itself.
The measurements will provide data to understand the nucleus internal structure, the nucleus nature and the mineralogical, chemical and isotopical composition. In fact Rosetta will be the first spacecraft to orbit a comet nucleus, the first spacecraft to fly alongside a comet as it heads towards the inner Solar System and the first spacecraft to analyze how a frozen comet is transformed by the heat of the Sun. After its arrival on the comet, the Rosetta lander will perform the first soft landing on a comet nucleus to study in-situ the comet nucleus composition.

Rosetta is the first space mission to travel beyond the main asteroid belt relying solely on solar cells for power generation, rather than the traditional radio-isotope thermal generators. The new solar-cell technology used on the orbiter's two solar panels (of 32 m in deployed configuration) allows it to operate over 800 million kilometres from the Sun, where solar radiation is only 4% of that on Earth. Hundreds of thousands of specially developed non-reflective silicon cells generate up to 8700 Watts in the inner Solar System and around 400 Watts for the deep-space comet encounter, what is in any case a very small amount to perform scientific experiments as foreseen.

2.2 Spacecraft Characteristics

The more interesting part for the probe is the lander Philae, so named in honour of the obelisk that had a bilingual inscription which provided to decipher the hieroglyphs of the Rosetta Stone. By Philae it will be possible to perform a microscopic studies of individual grains by the direct analysis of sample collected in-situ.

The SD2 drill and a sample distribution device will provide sample collection and distribution of the picked up soil.

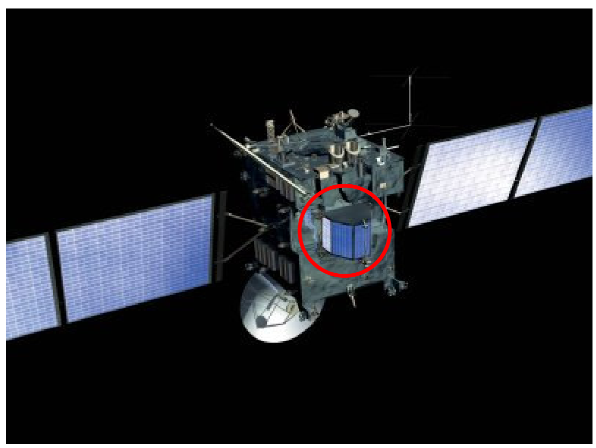

Fig. 3: Artist's imppression of the orbiter, and in the red circle there is lander

3. SAMPLING METHODS

The optimum strategy for taking samples depends on many factors, in particular on the required size and nature, or form, of the target object. A factor that affects greatly the sampling operation is the environment on target celestial body. These factors can be listed as: gravity, the material mechanical and chemical characteristics (solid rock, hard soil,

porous/spongy soil, liquid etc.), temperature range and solar radiation.
The most important environmental parameters (table II) for the design of SD2 are: comet strength, temperature and pressure at the comet surface, which are very poorly known.

Table II: Environmental parameters

Comet strength	50Pa – 50MPa
Temperature	-140°C (operation on comet); +50°C (no-operation)
Pressure	10^{-5}mbar (space vacuum); 1bar

3.1 Past in-situ surface analysis and sampling missions

Over the last decades, starting from the 1960's, robots and astronauts sampled in-situ some celestial bodies, Moon and Mars [6-7-8-9-10]. Particular attention has been paid to soil and rock sampling, analysis and methods to access subsurface samples. There is plenty of literature available about drill studies, mostly regarding the Russian and NASA's Moon missions. In the following part of the paper, designs and implementations of drilling and sampling devices will be described, as well as Russian mission to Mars and Venus, mission to Moon, European mission to Mars (Beagle-2) and Europe mission to comet.

Among the possible devices to soil sample robotically there are:

- Claw, scoop or trowel
- Tongs/pincers
- Drag lines and nets
- Drill (deep drill and surface drills) and corers
- Penetrators
- Drive tubes
- Passive/adhesive surfaces
- Brush sweeper
- Gas jets

It will focus our attention on the first five, the more successfully used.

3.1.1 Viking Scoop

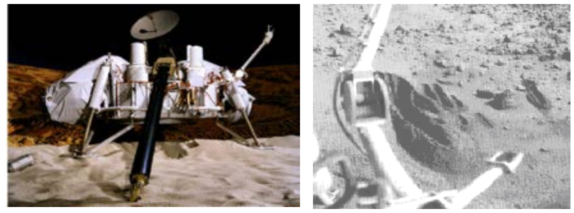

Fig. 5: Viking lander scoop

The scoop, figure 5, has been used during the Viking 1 and 2 missions to Mars in 1976-1982 and during the Venera missions to Venus in 1980's.
The Viking lander's sampling arm created a number of deep trenches as part of the surface composition and biology experiments on Mars. The digging tool mounted on the sampling arm could scoop up samples of material and deposit them into the appropriate experiment. Some holes were dug deeper in case of soil not affected by solar radiation and weathering.

3.1.2 Tongs/Pincer (MEE)

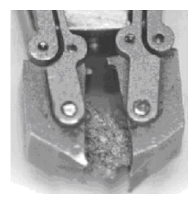

Fig. 6: Tong mounted on Surveyor Lunar lander

Tongs and pincers were developed for the Small Sample Acquisition system / Distribution Tool (SSA/DT) project. The Surveyor Lunar lander carried a "lazy-tongs" mechanism attached to an end of a robot arm, figure 6, to dig lunar soil.

3.1.3 Drill

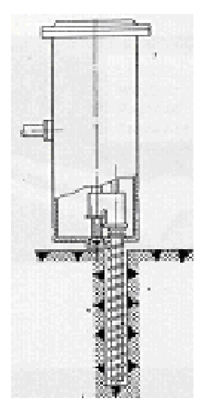

Fig. 7: Drill

Drill, figure 7, has been used so far in Luna, Apollo, Venera mission and in ongoing Rosetta cometary mission. The first one was the Russian Luna 16 drill: it was located on a robotic lander that returned its sample back to Earth.
During the Apollo 15-17 missions, astronauts used an hand drill, the Apollo Lunar Surface Drill ALSD, to retrieve subsoil samples. The Russian Venera landers had a robotic drill too.

3.1.4 Penetrometer

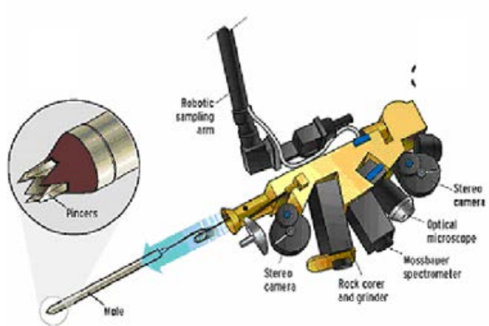

Fig. 8: Artist's impression of the Beagle 2 Penetrometer

The penetrometer, figure 8, is basically a stick that is pushed down in to the soil. Soil properties can be analyzed by combined several instruments that may acquire for example temperature, moisture, adhesion and electric properties. Penetrometers can be classified according to the penetrating method; impact or active and slow pushing force.
A mole, a kind of penetrometer, is connected to the lander by a tether instead of the rigid penetrometer structure. The Beagle 2 mission to Mars was supposed to use a mole, but unfortunately the landing was unsuccessful.
There were several penetrometer instruments onboard planetary landers, the first one was used in Lunokhod Moon rovers. A special case of penetrometer was the penetrating spacecraft, which lands on target body (comet, planet surface etc.). These surface penetrators have been designed to survive an hard impact, sending telemetry data on the properties of the penetrated surface back to orbiting spacecraft or directly to Earth. An example of a penetrator spacecraft is the twin Deep Space 2 penetrators, which was piggybacked to Mars aboard the Mars Polar Lander. They hit into Martian soil on December 3, 1999 but their faith is unknown, since they were never heard from.

3.1.5 Drive Tube

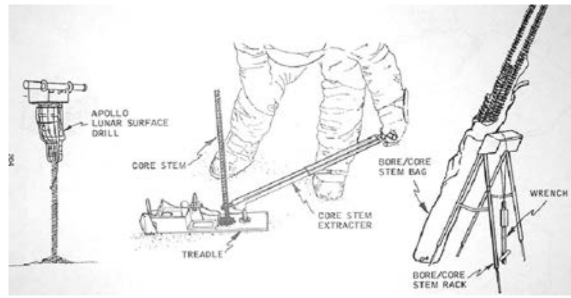

Fig. 9: Drive tubes used during Apollo missions

In Apollo missions three models of drive tubes , figure 9, were used to extract a soil sample for density analysis or the whole core sample from adhesive soil. Early tubes were sometimes hard to drive into the compact lunar regolith and did not always retain the core when removed. Apollo 15 and Apollo 16 used a larger diameter core tubes designed to work well. For that studies have been done to drive tubes for cometary, Mars surface and lunar sampling, down to a depth of about 10 cm. Required power between 0.5 and 1 W and sampling efficiency ranging from 1.2 to 6.6J per sample (1.9 cm^3 sample).

4. SD2 (SAMPLER DRILL AND DISTRIBUTION SUBSYSTEM)

SD2 subsystem, figure 10, provides comet samples collected at different depths and distribute them to the many instruments mounted on the base plate of Philae.

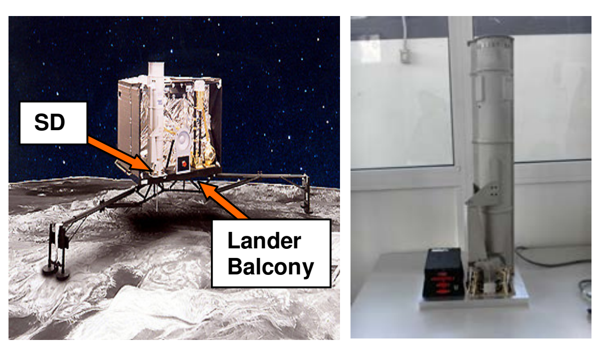

Fig. 10: Lander Philae (on the left), and SD2 closed configuration (on the right)

To this aim SD2 [11] is equipped with a drill able to collect several samples at different depths from the same hole or from different holes, to work in a particular environment, in fact on comet there are a very low gravity and a wide thermal excursion, and to execute all the operations with a very low power consumption.

SD2 is equipped by a Mechanical Unit and a Electronic Unit [12].

The total mass is about 5.1 kg with this distribution:

- Mechanical Unit ~ 3700 g
- Electronic Unit ~ 1000 g
- Harness ~ 400 g.

The power consumption during operations does not exceed the following levels:

- 1.5 W average power consumption in stand-by
- 6.0 W average power consumption during drilling/sampling operations
- 14.5 W max power consumption during drilling/sampling operations.

The **Mechanical Unit** is mounted at the Lander Balcony compartment in correspondence with a hole in the balcony dedicated to the drilling-sampling operations and will perform all electromechanical functions. In this unit there is the Tool Box, built with carbon fibre, that contains the drill-sampler tool in a protective structural shell which assures that no external contamination can reach the tools and actuators inside. The drilling and sampling functions are integrated in a unique auger. In this configuration there is the certainty to collect the sample at the established and measured depth, preventing hole collapsing during extraction or insertion of different tools. During the final phase of the drilling operation, the sampling mechanism, called Sampling Tube, picks the sample with a contact pressure. SD2 will deliver to the scientific instruments samples of tens of mm^3 (10-40) collected at a maximum depth of 230 mm. The sample collected is then discharged into the dedicated containers, the ovens (figure 11) mounted on the Carousel, the rotating disk that allows to displace the filled oven under the specific scientific experiment. The Volume Checker, figure 11, measures the total volume of the material discharged into the oven.

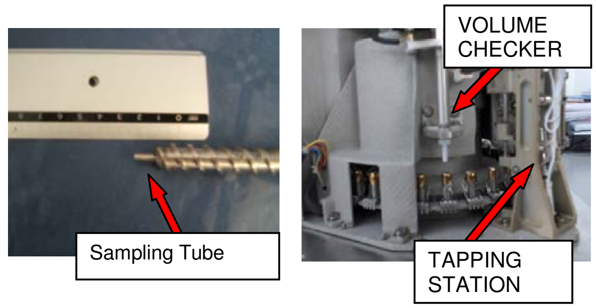

Fig. 11: Ovens, drill and sampling tube and tapping station, volume checker

The **Electronic Unit** is installed into the warm compartment of the lander and incorporates all electronics to control the Mechanical unit. It provides a SW and an HW platform to run which implements SD2 functions under higher level control system: the CDMS (Command Data and Management System) [13]. SD2 subsystem utilizes a Common Digital Processing Unit the C-DPU board, as micro-controller unit, that interfaces directly the CDMS. Data command interchange with the CDMS occurs exclusively on 16 bits word by word basis. The main functions of SD2 software are:

- Receive and execute commands from the CDMS. From CDMS, SD2 SW can receive Standard Commands, that can be sent by CDMS also to other units, and Specific Commands,
- Generate Telemetry Data autonomously collected by SD2 SW at the 4Hz default frequency. A specific command allows to change the acquisition frequency and to start the transmission to CDMS of collected data,
- Generate Housekeeping Data automatically requested by CDMS to SD2 SW, a word every 2s,
- Command the mechanical units motion by sending proper commands to the electronics unit,
- Perform the syntax and interface checks,

- Perform cyclic checks on the command motion,
- Activate recovery procedure in the case of a failure is detected.

5. SD2 ACTIVITY

Rosetta orbiter and Philae lander have to cover a long trip in Solar System, during these 10 years many activities have to be performed on board [14]. In fact, during the cruise phase, some passive and active checkouts are foreseen in order to evaluate the status of system. For what concerns SD2, during these link windows, the switching sensors, the carousel rotation and the drill rotation will be performed and monitored.

All these procedures are implemented by the laboratory of Aerospace Department at Politecnico di Milano. The laboratory goal consists in the improvement of drilling and sampling performances. The achievement of this goal is based on the exploitation of SD2 Flight Spare (FS), which is actually available at the same laboratory, on the design and realization of a test facility and finally on the development of a methodology for the characterization of the soil properties from drill telemetry data. The laboratory instrumentation consists in an Electronic Ground Support Equipment (EGSE) that is used for a first verification of specific command sequence and for the first mission plan check. Moreover to operate in a more realistic way and to evaluate the SD2 behaviour in different scenarios, a dedicated facility has been design and realized [15] (figure 12).

The most critical phase is the on-comet one because it will be possible to face many different conditions. For example the mission success depends by the landing site and by the drilling strategy. To this aim, with this facility, it is possible to reproduce many different environment and situations to set up SD2 to the meeting with the comet.

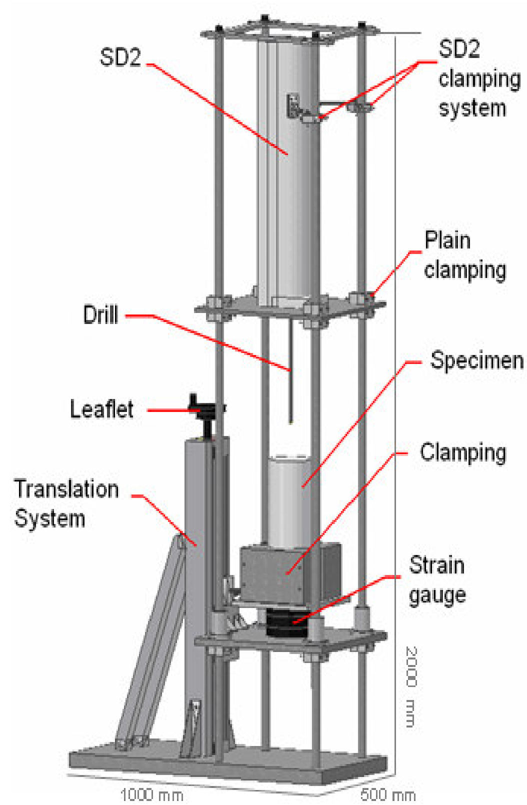

Fig. 12: Autocad Picture of the facility structure

This facility is equipped with a support structure (for the easy inspection) a sensor system to measure the drill cinematic behaviour, a translation system (figure 13) to simulate all possible conditions of comet soil (for example the eventual presence of rises or of depressions), and also some specimens (travertine to simulate comet soil, marble to simulate small stone and "comet analogue"). Thank to this facility it is possible to perform:

- FS mechanical and functional checking in different environmental conditions
- Comet soil simulation
- Mechanical sample behaviour
- Foreseen operation activities implementation
- Non common activities or emergency procedures implementation
- Experimental correlation between drill movement and soil characteristics.

Fig. 13: Picture of the laboratory

CONCLUSIONS

The passive and active checkouts already performed in order to evaluate the status of the system show that SD2 activity is consistent with the expectations .

The activities, now in progress at the laboratory at Politecnico di Milano, will allow to test different mission plans, to simulate several different landing scenarios and to implement suitable strategies to face emergency conditions. Furthermore, following a method newly developed, it seems possible to establish a correlation between the drill movements and the soil characteristics. This very exciting opportunity to access to cometary mechanical properties further increases its scientific value.

Future space missions for Solar System exploration, that require in situ analysis, will take advantage from the experience gained through SD2.

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